Faculty of Mechanical Engineering

A SIMULATION STUDY ON TEMPERATURE NON-UNIFORMITY OF PHOTOVOLTAIC THERMAL USING COMPUTATIONAL FLUID DYNAMICS

Irfan Alias Farhan

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IRFAN ALIAS FARHAN

A report submitted
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DECLARATION

I declare that this report entitled "A simulation study on temperature uniformity of photovoltaic thermal using computational fluid dynamics" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : Irfan

Name : Irfan Alias Farhan

Date : ______________________

APPROVAL

I hereby declare that I have read this report and in my opinion, this report is sufficient in terms of scope and quality for the award as partial fulfilment of Master of Mechanical Engineering (Energy Engineering).

Signature : ___________________________________

Supervisor Name : Dr Mohd Afzanizam Mohd Rosli_____

Date : ___________________________________

DEDICATION

Dedicated to my beloved family and friends. Especially, Dr Kamran Latif and Dr Mohd Afzanizam Mohd Rosli for their incredible support.

ABSTRACT

Energy generation from fossil fuels is the leading source of global greenhouse gas (GHG) emissions. With climate change being one of the biggest problems faced by modern society increasing energy supply by more production from fossil fuel would lead to quicker depletion of these resources and more pollution. To avoid the depletion of natural resources and to produce energy without harming the environment, renewable energy resources such as solar energy are being incentivized. PV technology utilizes solar energy to generate electricity and thermal energy. However, Photovoltaic (PV) cells operate at a lower efficiency at high operating temperatures. To enable the high-efficiency operation, photovoltaic thermal (PVT) systems are utilized. PVT aims to take the thermal energy away for PV cells and utilize it in other applications. The temperature distribution across the PV plate in most PVT systems is not uniform leading to regions of hotspots. The cells in these regions perform less efficiently leading to an overall lower efficiency of the PV plate. They can also be permanently damaged due to high thermal stresses. In this study, a custom absorber for a PVT is designed based on literature to provide a more even temperature distribution across the PV plate. The absorber design is tested via computational fluid dynamics (CFD) simulation using ANSYS Fluent 19.2 and the simulation model is validated by an experimental study with the percentage error in the range of 5.75% - 8.5%. The custom and the serpentine absorber utilized in the experiment are simulated under the same operating conditions having water as the working fluid. The custom absorber design is found to have a more uniform temperature distribution on more areas of the PV plate as compared to the absorber design utilized in the experiment, which leads to a lower average surface temperature of the PV plate. This results in an increase in thermal and electrical efficiency of the PV plate by 3.21% and 0.65% respectively. The new absorber is also tested at various mass flow rates and solar irradiance levels to understand the effect of said parameters on the performance and temperature uniformity of the PVT system. The new absorber design has an estimated thermal and electrical efficiency of 49.46% and 13.87%, respectively at 30 kg/h and 1000 W/m^2.

ABSTRAK

Tenaga yang dihasilkan melalui penggunaan minyak mentah merupakan penyumbang utama untuk kesan gas rumah hijau. Penggunaan minyak mentah yang tinggi juga akan menyebabkan sumbernya menjadi semakin berkurangan ditambah pula lagi dengan pencemaran alam sekitar. Untuk mengatasi masalah kekurangan sumber minyak mentah dan pencemaran udara ini, tenaga yang boleh diperbaharui seperti tenaga solar ini dilihat sebagai salah satu jalan penyelesaian. Panel fotovoltan termal daripada sumber tenaga solar boleh menghasilkan tenaga elektrik dan kuasa haba. Namun panel fotovoltan beroperasi pada kadar kecekapan yang rendah kerana kesan pemanasan tenaga haba yang diserap pada panel fotovoltan. Oleh yang demikian, penyejukan untuk solar panel solar, mampu meningkatkan kadar kecekapan panel solar. Selain itu, masalah yang dihadapi adalah tenaga haba pada permukaan panel solar tidak sekata. Ini juga boleh menyebabkan kerosakan pada sel solar. Dalam kajian ini, sistem penyejuk termal telah direkabetuk dan pengujiannya secara simulasi untuk mendapakan kesan suhu yang lebih sekata. Simulasi menggunakan perisian Pengkomputeran Dinamik Bendalir ANSYS. Terlebih dahulu, simulasi ini telah disahkan berdasarkan keputusan penyelidik terdahulu yang menjalankan kajian secara eksperimen. Didapati yang peratusan perbezaan antara eksperimen dan simulasi adalah antara 5.75% - 8.5%. Sistem penyejuk yang direka khas ini disimulasi dalam keadaan suhu air yang malar, kadar alir jisim dan keamatan suria. Ia menunjukkan panel solar ini mempunyai suhu yang lebih sekata dan kadar kecekapan panel solar dari segi haba dan elektrikal meningkat sebanyak 3.21% dan 0.65%. Sistem penyejuk termal baharu ini juga diuji pada kadar alir dan keamatan tenaga suria yang berbeza bagi menunjukkan kesan setiap parameter kepada kecekapan dan suhu yang sekata pada sistem fotovolta terma. Sistem penyejuk termal baharu ini mencatatkan kecekapan termal dan elektrik setinggi 49.46% dan 13.87%, pada kadar alir 30kg/h dan keamaatan tenaga solar 1000 W/m2.Kesimpulannya, rekabentuk yang dicadangkan berjaya dihasilkan bagi mendapatkan pemanasan sekata sekaligus meningkatkan kecekapan elektrik dan kecekapan terma pada system fotovoltan terma yang telah direkabentuk.

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3D	3 Dimensional
CFD	Computational Fluid Dynamics
CPC	Compound Parabolic Concentrator
c-Si	Crystalline Silicon
EVA	Ethylene Vinyl Acetate
FPC	Flat Plate Collector
GHG	Greenhouse Gas
LFR	Linear Fresnel Reflector
PDC	Parabolic Dish Collector
PTC	Parabolic Trough Collector
PV	Photovoltaic
PVT	Photovoltaic Thermal

CHAPTER 1

INTRODUCTION

1.1 Project background

The energy demand has seen a sudden increase in recent years due to the increase in population and the rapid advancement of technology (T. Ahmad and Zhang 2020). According to the International Energy Agency, global energy consumption rates are expected to rise by up to 37% by 2040 (Sardouei, Mortezapour, and Jafari Naeimi 2018). With the increase in demand for energy comes the need to supply more energy. Increasing the supply with non-renewable natural resources such as fossil fuels, natural gas, coal etc will lead to an increase in the depletion range of these resources. Fossil fuels are a major contributor to energy generation. Energy generation from fossil fuels is the leading source of global greenhouse gas (GHG) emissions (Meng et al. 2020). With climate change being one of the biggest problems faced by modern society increasing energy supply by more production from fossil fuel would lead to quicker depletion of these resources and more pollution. To avoid the depletion of natural resources and to produce energy without harming the environment, renewable energy resources such as solar energy, hydro, wind, biomass, etc are used to generate electricity (Mbungu et al. 2020). Solar energy is one of the best options due to its high potential and availability across many regions around the globe. Solar energy is utilized in many ways using various technologies. One such technology is called Solar Photovoltaic (PV) system that uses solar energy to generate electricity and thermal energy. However, the majority of solar irradiation is converted into thermal energy. Solar PV systems are still considered to be quite an expensive source for electrical energy generation due to inefficient technology as most of the solar energy is converted into thermal energy. Because of this, solar PV systems only have electrical efficiency in the range of 4-17% depending on the operating conditions (Hosseinzadeh et al. 2018). Even though it is inefficient, solar power still possesses the most potential for power generation (Walmsley et al. 2018).

It is a widely known fact that the electrical efficiency of solar photovoltaic panels decreases with an increase in operating temperatures (Bahaidarah Baloch and Gandhidasan, 2016). For this reason, various cooling techniques are utilized in Solar Photovoltaic Thermal (PVT) systems. Solar PVTs extract the heat from the PV panel into a working fluid flowing through an absorber so that the PV cells can operate at lower temperatures and the thermal energy is utilized in some other application (Al-Waeli et al. 2016; H. M. S. Bahaidarah Baloch, and Gandhidasan 2016; Khelifa et al. 2016).

The performance of the PVT system depends heavily on operating conditions. This is explored to a high degree in literature. However, temperature uniformity also affects the performance of a PVT system. Non-uniform temperature distribution results in regions of hotspots (areas of high temperatures). The cells in these regions perform badly compared to other cells due to high temperature resulting in a decrease in efficiency due to lower power generation. These temperature hotspots can also cause permanent damage to the PV cells due to high thermal stresses. Therefore, temperature uniformity is an important factor in increasing the performance and the lifetime of PV panels (H. M. S. Bahaidarah, Baloch, and Gandhidasan 2016)

This study aims to provide a PVT system with a custom absorber configuration which will ensure an improved and more uniform temperature distribution across the PV plate. This custom absorber will be optimized based on the previous literature. This new absorber design should give better temperature distribution across the PV plate surface, which will help with prolonging the lifetime of the panel and its overall efficiency.

1.2 Problem statement

There is an extensive array of knowledge available in the literature around the globe on solar PVT systems. Despite that, there are still some issues that are prevalent and need to be studied more. The problems at the core of this project are detailed below:

- Most of the power production around the world is based on fossil fuels. The reservoirs of fossil fuels are depleting at an accelerated rate due to an increase in power demand. On top of that, power generation by fossil fuels leads to pollution as well. For these reasons, the reliance on fossil fuels for power generation needs to be eradicated for a strong and healthy future of humankind. Promoting the use of renewable energy resources for power generation using technologies such as the solar photovoltaic panels builds towards this future.
- Photovoltaic cells generate thermal energy in the process of converting solar energy into electrical energy. The thermal energy generated results in increased operating temperature for the cells. The electrical efficiency of PV cells decreases with an increase in the operating temperature of the PV cell. The generated thermal energy also leads to permanent damage to the cells due to high thermal stress levels. This thermal energy is taken away from the cells using PVT systems. Many studies have been done to improve heat transfer in PVT systems to maximize their efficiency.

- However, there still exists the problem of non-uniform temperature distribution across the PV cells. There have not been many studies focused primarily on improving the temperature distribution on the PV plate. Non-uniform temperature distribution leads to regions of high temperatures on the PV plate known as hotspots. These hotspots are problematic because the cells in these regions have a lower electrical efficiency due to higher operating temperatures. High thermal stresses can also cause permanent damage to the cells in hotspots. Result of non-uniform temperature distribution on the PV panel causes a decrease in overall efficiency. Because of these reasons, the performance of PV panels is usually determined by the hotspots. So, there is a need to better understand what causes this non-uniform temperature distribution so that it can be minimized.

1.3 Objective

The following research objectives are set for this project:

- To propose a new absorber based on the spiral absorber design which will provide a uniform temperature distribution on PV.
- To evaluate the temperature uniformity using the new absorber design.
- To determine the efficiency of the new absorber design.

1.4 Scope

The scope of this project is to perform a simulation study to check the performance and temperature uniformity of a photovoltaic thermal (PVT) collector using a custom absorber design. The performance and the temperature uniformity of this custom absorber are compared with the PVT system from an experimental study taken from the literature. The detailed description of the scope is given below:

1. A literature review is carried out to understand the concept, working and designs of the PVT systems. The parameters affecting the performance of the PVT systems are discussed including temperature uniformity.
2. The new absorber design is analyzed by using CFD-ANSYS software. The simulation model is 3D, and the analysis is carried out only in laminar flow design.
3. The simulation model is validated by an experimental study taken from literature.
4. The temperature uniformity and the performance of the PVT system are tested with different solar irradiance and mass flow rate levels to find out their effect on temperature uniformity and performance.

1.5 Report outline

Briefly, this report contains five chapters. Chapter one explains about the introduction, problem statement, objective, scope, general methodology, and report outline of the project.

Next, the literature review is in chapter two which reviews previous research and sources obtained from journals, articles, reports, books, and web sites to find the information related to this study. The aim of this chapter is to create a guideline from previous knowledge and ideas in order to complete this project. The information selected based on the objective of this project. For instance, the information about solar energy, solar photovoltaic cells, photovoltaic thermal systems, and more are obtained to achieve the set of objectives.

Chapter three will describe the method used in this project to get the desired results. This chapter describes details on the preparation of the simulation model, grid independence test and the custom absorber design will be covered.

Furthermore, chapter four discusses the results obtained from the study. All of the results will be collected and analysed. The validation of this project also will be shown in this chapter

Lastly, chapter five will conclude all the overall findings of this project. This chapter also suggests several recommendations for future work related to this project in order to improvise the result.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar energy

Solar energy is one of the best options for clean, green, and renewable energy resources due to its high energy potential and accessibility across many regions around the globe (Kannan and Vakeesan 2016). **Figure 2.1** shows the potential power of the incident solar irradiance across the globe.

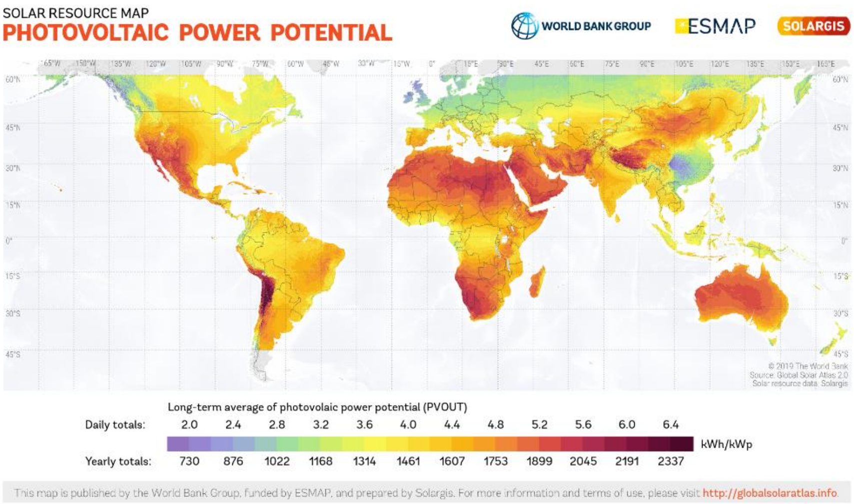

Figure 2.1: Global photovoltaic power potential map (Global Solar Atlas 2020)

2.2 Solar photovoltaic

Solar photovoltaic (PV) is a technology used to generate electric power from sunlight. When the sunlight falls on the PV cells, the electrons are activated from a lower energy state to a higher energy state. This will create holes and free electrons in the semi-conductor, thus creating electricity. Commonly used semi-conductors are Monocrystalline silicon, polycrystalline silicon, copper indium diselenide etc (Kannan and Vakeesan 2016). However, solar PVs are considered to be quite an expensive source for energy generation due to inefficient technology (Walmsley et al. 2018). Even though the technology is inefficient, solar power still possesses the most potential for power generation (Walmsley et al. 2018). Therefore, a lot of research work is being done to improve the technology in recent years. Photovoltaic cells are used to convert solar energy into electrical energy and thermal energy is produced as well. PV panels typically have electrical efficiency in the range of 4-17% (Hosseinzadeh et al. 2018).

Figure 2.2: PV cell (MrSolar 2014)